AD-A047 235 NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF F/G 8/3
SUSPENDED SEDIMENTS MEASURED IN THE SURF ZONE.(U)
SEP 77 W D MORRIS

UNCLASSIFIED NL

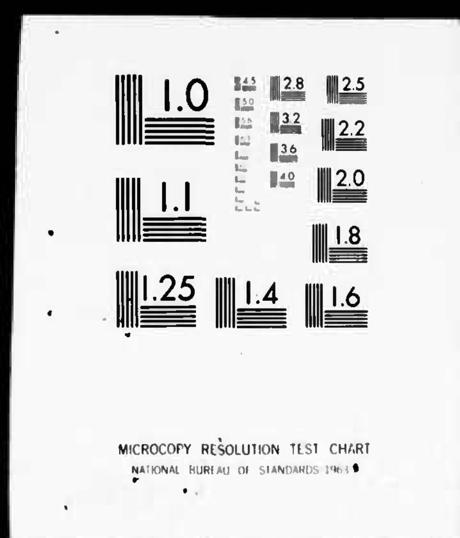
1 OF 1

ADA047 235

END
DATE
FILMED
1 - 78
DDC

1 OF 1

ADA047 235



NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SUSPENDED SEDIMENTS MEASURED
IN THE SURF ZONE

by

William Denton Morris

September 1977

Thesis Advisors: Edward B. Thornton
Stevens P. Tucker

Approved for public release; distribution unlimited.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

6 Suspended Sediments Measured in the Surf Zone. .

5. TYPE OF REPORT & PERIOD COVERED

9 Master's Thesis,
~~September 1977~~

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10 William Denton Morris

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Naval Postgraduate School
Monterey, California 93940

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

Naval Postgraduate School
Monterey, California 93940

12. REPORT DATE

11 Sep[redacted]77

13. NUMBER OF PAGES

48 12 47p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Nephelometer
Optical Oceanography
Surf Zone
Suspended Sediments

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Suspended sediments were measured optically within the surf zone at Torrey Pines Beach, California. Sediment laden water was sampled through three intake nozzles which were mounted on a tower along with the optical sensor (nephelometer) which was in line with the sediment laden water which was pumped to the shore. The nephelometer gave a time series of the suspended sediments.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601 |

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 450

The water pumped to the beach was filtered to obtain total sediment concentration. Horizontal velocities were measured simultaneously with an electromagnetic current meter mounted on the same tower. During the experiments the breaker height ranged between 1 and 2 meters and the mean period between 8 to 16 seconds. The peaks of the nephelometer spectra occurred at approximately twice the peak frequency in the velocity spectra indicating two or more maximas per wave period. Cross spectra were computed between suspended sediments and horizontal velocity. A maximum coherence ranging above .7 occurred at the first harmonic of the peak wave frequency. The suspended sand was well sorted quartz with a mean grain size of 0.15 mm.

Suspended sand concentration appeared to decrease exponentially with height above the bottom with the rate of decrease and total concentration related to the mean bed shear stress. Mean sand concentration ranged between 0.05 to 0.32 grams of sand per liter of sea water.

Suspended Sediments Measured in the Surf Zone

by

William Denton Morris
Lieutenant, United States Navy
B.S., United States Naval Academy, 1972

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 1977

Author William Denton Morris

Approved by: Edward B. Thornton
Thesis Advisor

Stevens P. Tucker
Co-Advisor

Dale F. Leipper
Chairman, Department of Oceanography

Dean of Science and Engineering

ABSTRACT

Suspended sediments were measured optically within the surf zone at Torrey Pines Beach, California. Sediment laden water was sampled through three intake nozzles which were mounted on a tower along with the optical sensor (nephelometer) which was in line with the sediment laden water which was pumped to the shore. The nephelometer gave a time series of the suspended sediments. The water pumped to the beach was filtered to obtain total sediment concentration. Horizontal velocities were measured simultaneously with an electromagnetic current meter mounted on the same tower. During the experiments the breaker height ranged between 1 and 2 meters and the mean period between 8 to 16 seconds. The peaks of the nephelometer spectra occurred at approximately twice the peak frequency in the velocity spectra indicating two or more maximas per wave period. Cross spectra were computed between suspended sediments and horizontal velocity. A maximum coherence ranging above .7 occurred at the first harmonic of the peak wave frequency. The suspended sand was well sorted quartz with a mean grain size of 0.15 mm.

Suspended sand concentration appeared to decrease exponentially with height above the bottom with the rate of decrease and total concentration related to the mean bed shear stress. Mean sand concentration ranged between 0.05 to 0.32 grams of sand per liter of sea water.

TABLE OF CONTENTS

ACKNOWLEDGEMENT

The best way I feel that I can express my thanks to all the people that I had the pleasure of working with during the course of my thesis, to name just a few, my co-advisors Professors Thornton and Tucker of the Oceanography Department, Bob Smith of the Naval Postgraduate School Research Foundation, MR1 Adams at the Machine Shop, and the whole gang down at Scripps Institute, is to say that I could never have hoped to receive a more total experience than this one has been for me. From start to finish I have learned things that have taught me how difficult and rewarding Oceanographic field work can be, things that have resulted in a knowledge and an appreciation that will remain with me always.

I. INTRODUCTION

The measurement of sediment transport along a beach and its correlation with the wave environment is an extremely difficult task. Hence, only a very limited amount of data is available. Many difficulties in making sediment transport measurements are associated with working in the extreme environment of breaking waves. The mounting of instruments also presents problems because artificially induced scouring or perturbations of the flow field around support towers must be avoided; evidence suggests that measurements around piers may not be valid for this reason.

Interpretation of the data once it has been collected is complicated by the fact that a satisfactory physical model of sediment transport under waves does not exist. Four major reasons for the lack of an adequate model are given by Nakato, et al (1977). First, the motion of the fluid is non-uniform, unsteady, and at least two dimensional. Second, the fluid has two free surfaces (the air-water and the water-bed interfaces) when one considers that boundary conditions must be prescribed on surfaces whose positions are unknown except for where they are deduced to be. Third, the interaction between the fluid and solid phases of the flow field is so complicated that formulas describing it have yet to be satisfactorily derived. Fourth, the presence of sediment in suspension in a fluid can change the characteristics of the flow field which in turn can affect the sediment motion.

Sediment transport is generally considered to be composed of two modes of transport, bedload and suspended. Bedload transport is the rolling of the grains along the bottom and includes the fluidized bed. The suspended sediments are defined as that portion that is above the bed. This paper deals only with suspended sediment transport.

Attempts to measure suspended sediments in the field, both in the surf zone and in deeper water, have involved a variety of techniques including the use of fluorescent dyed sand tracers, a variety of sediment traps, optical devices and acoustic devices. Fluorescent tracers are not discussed here since this technique primarily measures bedload transport. Some of the above mentioned methods used in deeper water date back as far as the late 1800's and early 1900's.

The earliest published information on the distribution of sand transport along the beach profile for prototype conditions was by the Beach Erosion Board (1933). The distribution of longshore current and suspended sand obtained from water samples was measured from piers extending across the surf zone. These measurements demonstrated that the greatest sand transport occurred at the breaker line, where the turbulence was a maximum, and decreased shoreward with another peak in the swash zone--another area of high turbulence. Seaward of the breakers, the sand transport decreased with increasing depth. Watts (1953) conducted similar studies from a pier using a more elaborate continuous suspended sediment sampler. He also measured vertical distributions. The results were qualitatively similar and showed that the amount of sand in suspension was related to the wave height, or energy, of the waves for a particular test. Fukushima and Mizoguchi (1958) and Homma and Horikowa (1965) used suspended samplers made of bamboo poles to measure the vertical distribution of suspended sediments. The data showed that the amount of suspended sediment in the swash zone and near the breaker line can be fairly evenly distributed over the vertical due to the high degree of turbulence throughout the water column. This is particularly true at the breaker line where a large vertical velocity component can be present in the case of plunging breakers.

The principles of measuring particulate concentrations using a light emitting source have been discussed by Jerlov (1968) and have been summarized in a paper by Das (1972). Longinov (1968) was probably the first to use photocells to measure suspended sediment concentrations in the nearshore zone. The most recent optical studies in the surf zone are those of Brenninkmeyer (1973, 1974), who used an instrument he named the "almometer." The almometer consisted of 64 photo-electric cells opposite a high intensity fluorescent lamp which measured sand concentrations in the bottom 1.2 m of water simultaneously and continuously. A disadvantage of this instrument is that it must be used at night.

The optical device described in this paper was designed to obtain a time series of the suspended sediments at any one of three levels in the surf zone while at the same time taking an actual sample of the suspended sediments. Variations in the water surface elevation and water particle velocities were measured simultaneously with the suspended sediment concentration with the objective of relating the suspended sediment concentration to the forcing function.

II. NEPHELOMETER

A general name applied to instruments that measure concentrations of suspensions by means of transmitted light is the nephelometer. Some unique problems arise when using optical devices to measure suspended sediment transport in the surf zone. The calibration of the optics is very difficult due to the unknown scattering characteristics of the sediment. Breaking waves entrain large amounts of air and inject bubbles down into the water column. Bubbles are effective light scatterers and therefore make absolute calibration very difficult. Further, the physical mountings of the instrumentation can act as a disturbance to the flow field and can induce artificial sediment transport that is many orders of magnitude greater than the natural transport. Our measurement device was designed to minimize these difficulties.

The sampling system is shown schematically in Figures 1 and 2. Three intake nozzles were mounted on a 4-m high tower in the surf zone through which the water was sampled. The water was pumped through a 2.54-cm (1-in.) pipe buried in the sand to the shore and discharged into settling buckets in order to determine sediment concentration. The nephelometer was in-line with the sampled water and mounted on a surf zone tower to determine the instantaneous suspended sediment concentrations. A photograph of the tower exposed at low tide is shown in Figure 3.

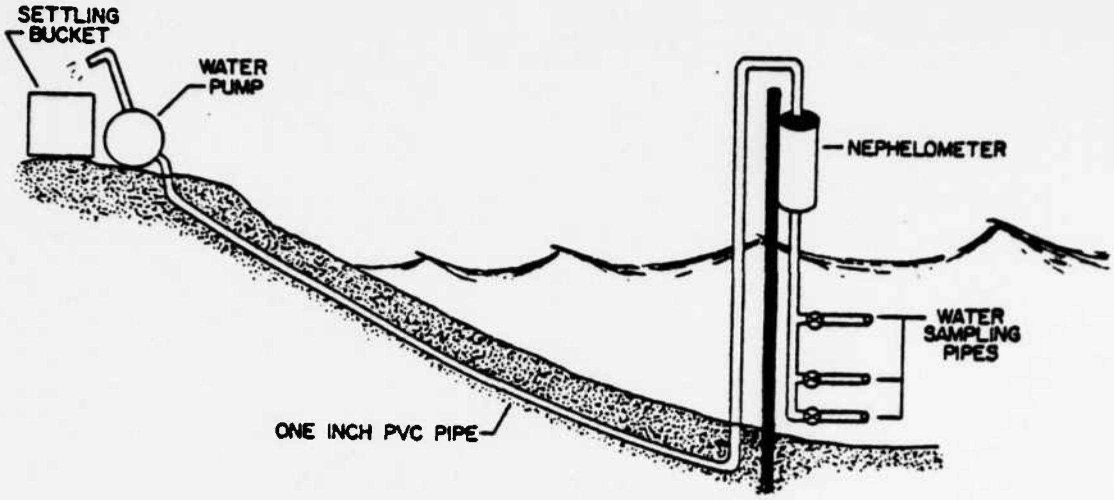


Figure 1. Nephelometer Sampling System.

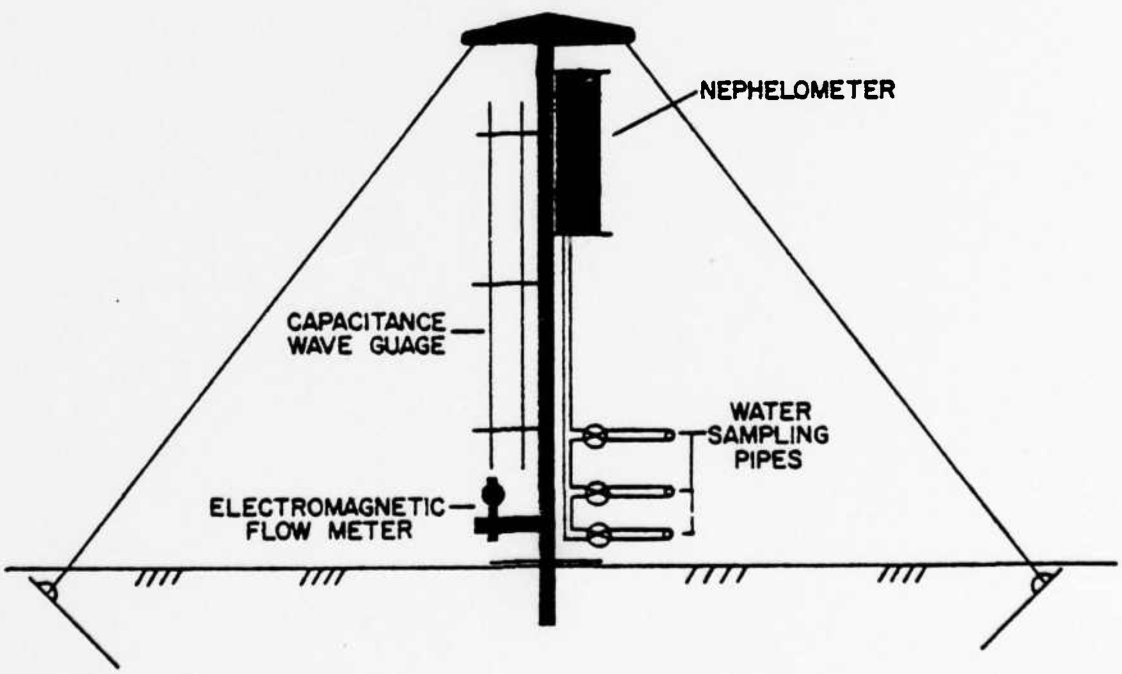


Figure 2. Instrumentation Tower.

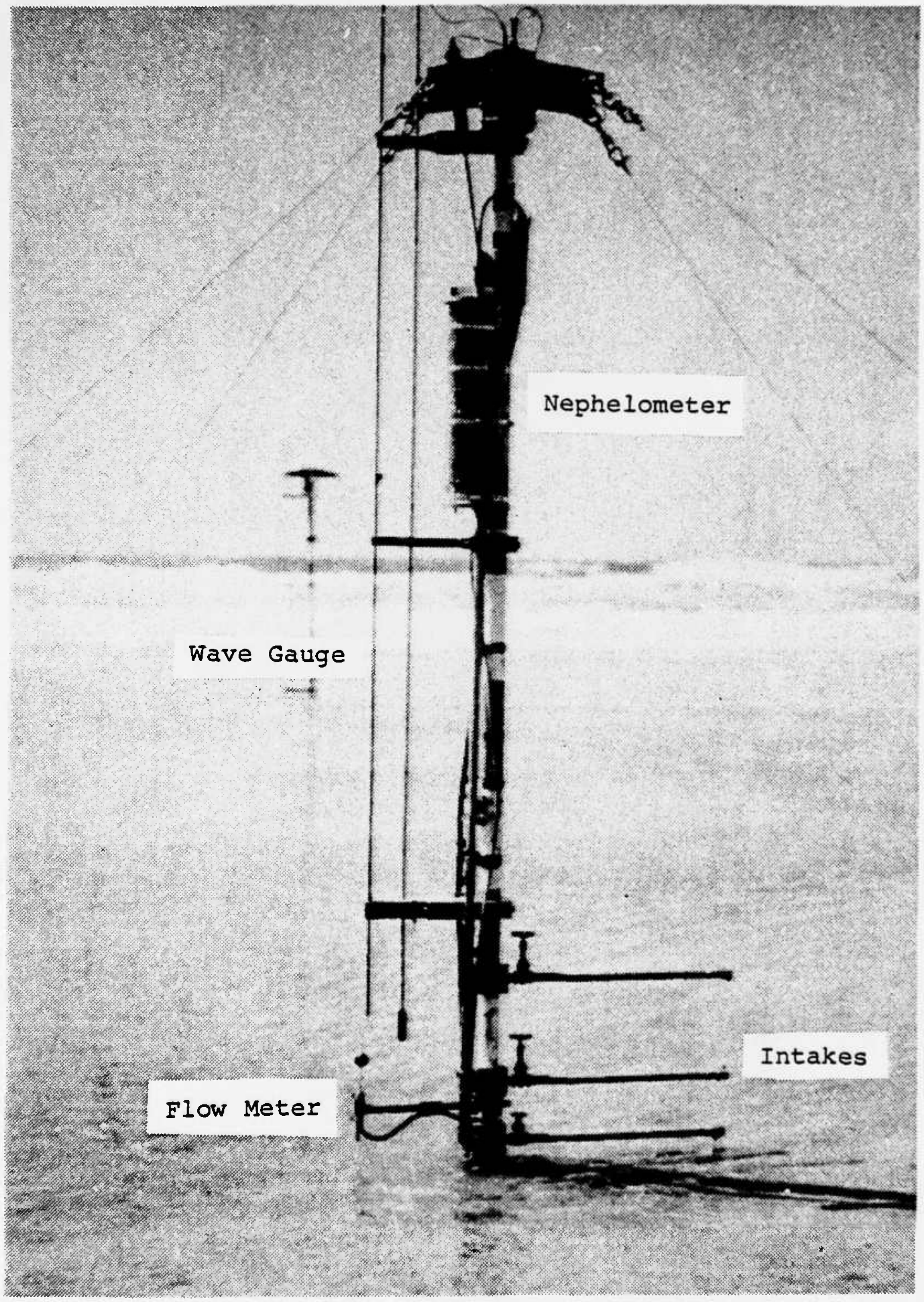


Figure 3.

The nephelometer used in this experiment generated voltage fluctuations as a result of differences in the intensity of forward scattered light measured at a 45° angle. The differences in scattering intensity were caused as water from a selected depth in the surf zone, with its different concentrations of sediment, passed through the system (see Figure 4). In addition, the system was designed to take samples of sea water from any one of three different depths whenever it was desired. This allowed actual mean concentrations of suspended sand to be derived and an _in situ_ calibration of the nephelometer.

The three 1.9-cm (3/4-in.) diameter intake nozzles were arranged vertically and separated by distances of 30.5 cm and 17.5 cm from top to middle, and middle to bottom, respectively. Each intake nozzle has a valve that allowed it to be turned on or off, thus allowing a sample to be taken from one selected level at a time. The pipe used for the intake nozzles extended 76 cm away from the support tower to minimize sampling any artificially induced sediment transport by the 6.3-cm (2½-in.) diameter pipe tower. A screen with a .5-cm mesh was placed on the end of each intake nozzle to prevent large pieces of kelp and other detritus from blocking the system. These screens were checked every few minutes during the sampling periods to insure they were clean.

A 2-hp pump was used to pull the water sample the approximate distance of 150 m from the intake nozzle to the settling bucket. The required pumping rate was based on

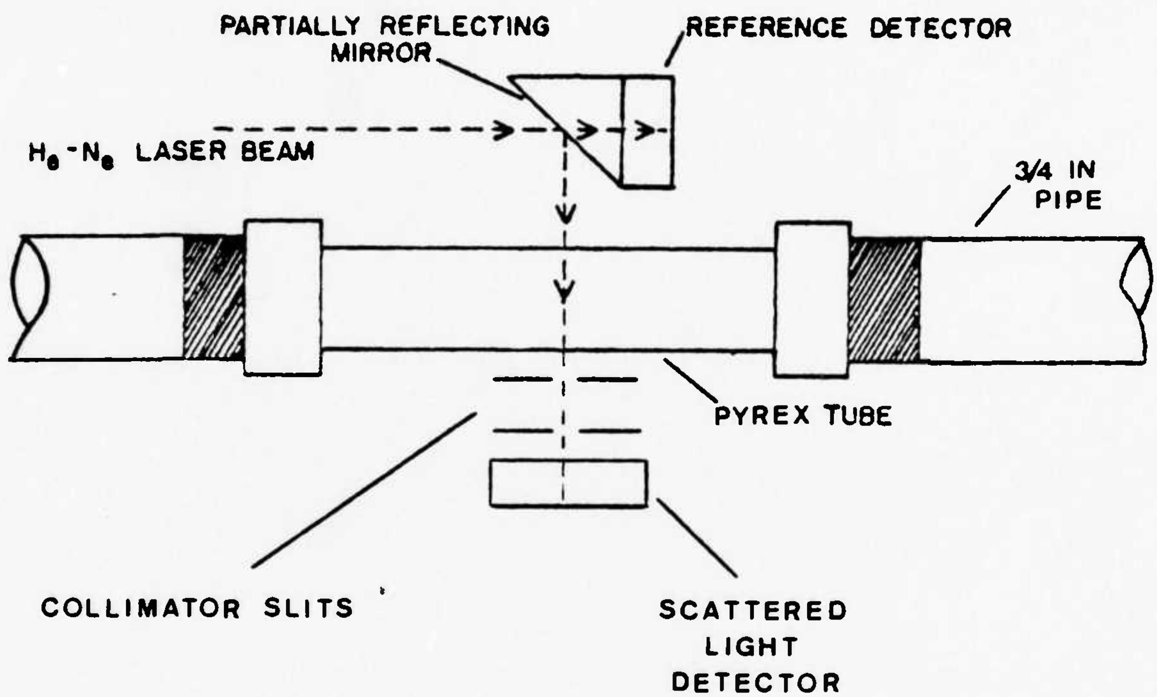


Figure 4. Optical Path.

satisfying both lower and upper limits. The lower limit insured that all particles stayed in suspension while the water flowed through the system. The upper limit insured that the flow field in the water column outside the intake nozzle was not distorted, causing samples to be taken from elevations other than the one selected. Using hydraulics theory, it was determined that the lower and upper limits would need to be between 90 cm/sec and 300 cm/sec, respectively. During the experiment the observed velocities through the system ranged from 93 cm/sec to 102 cm/sec, within the prescribed limits. Visual observations of the flow field outside the intake nozzle and the system's piping further indicated that the ocean water was being properly sampled. The sampled water was pumped into a large container of known volume located at the landward end of the system. The pumping rate was determined by the length of time required to fill the container.

The water taken in through the selected intake nozzle was passed up the pipe approximately 2 m and through an in-line pyrex tube which was housed in a 15.2-cm (6-in.) diameter, water and light proof cylinder containing the nephelometer. It then passed out of the cylinder and into a 2.54-cm (1-in.) p.v.c. pipe through which it traveled the rest of the distance to the settling bucket.

The nephelometer consisted of a light source, reference detector, scattered light detector, and divider circuit to ratio the scattered to the referenced light (see Figure 5).

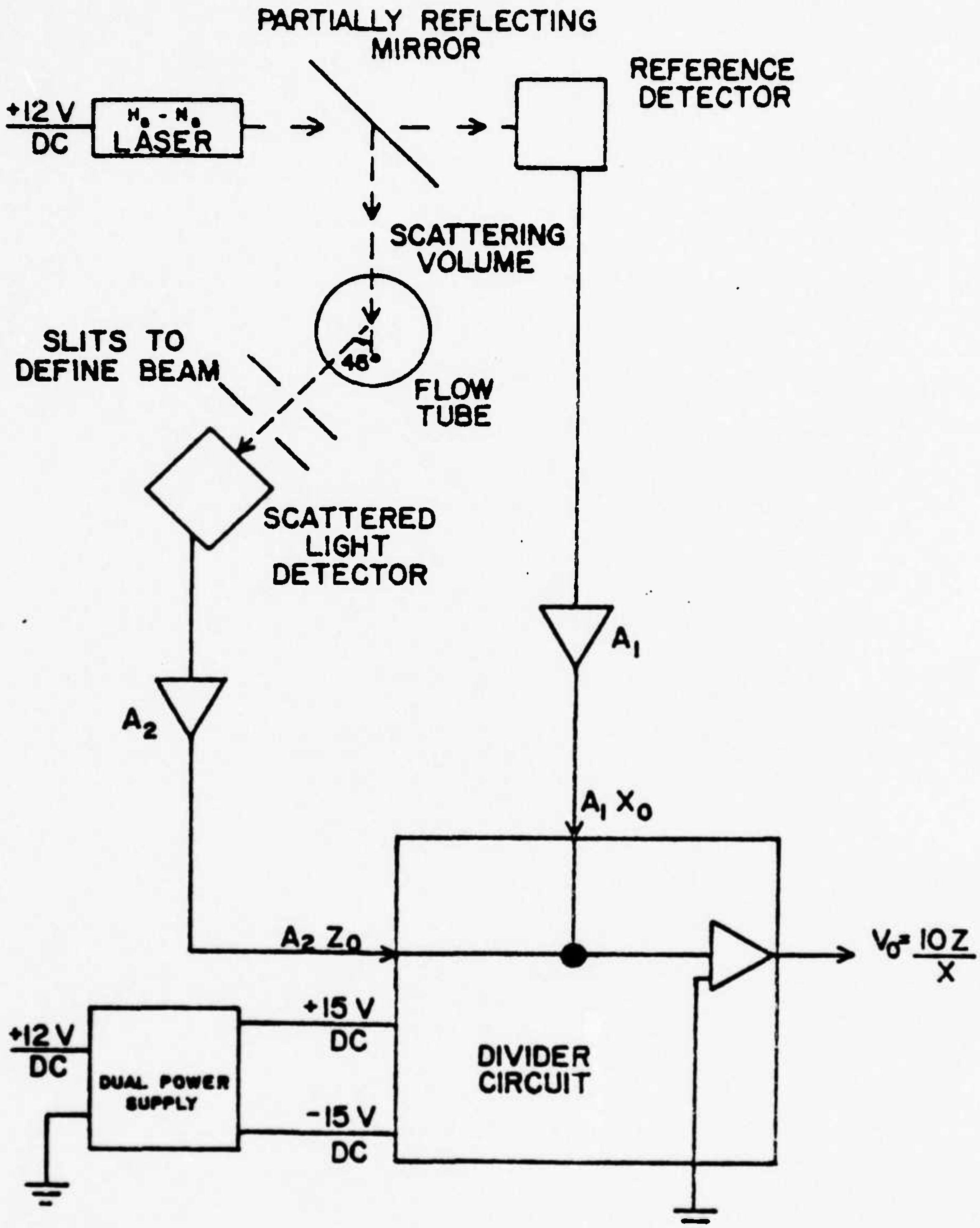


Figure 5. Nephelometer Electronics.

The light source was a Metrologic model 620D helium-neon laser which provided a well-collimated light beam approximately 1 mm in diameter. Next in line along the light path from the laser was a semi-transparent mirror designed to allow 15 percent of the light to pass through it into a reference photo detector, a United Detector Technology Inc. PIN-10 Schottky barrier photodiode. The remaining 85 percent of the laser light was reflected at a 90° angle and passed perpendicularly through the glass tube where it scattered off of the water and suspended particles within. In the third plane, looking at the forward scattered light at a 45° angle, was another photo detector, a UDT 500 Schottky barrier photo diode which had its own amplifier to increase the low voltages which resulted from the much smaller light levels detected by it. A collimator was placed between the scattering detector and the glass tube in line with the 45° forward scattering angle to enable an accurate scattering volume to be determined.

The voltage outputs from the reference light and scattered light detectors were then amplified by 741 op amps and fed into an Analog Devices 533 divider circuit which assigned X values to the reference light voltage, Z values to the scattered light voltage and then gave a signal out of $10 \frac{Z}{X}$. A ratio of the scattered light to reference light was used so that any fluctuations in the light source would be compensated for. The signal was sent to the beach via a 7 conductor, shielded and armored cable where it was then transmitted to recording facilities at Scripps Institute.

The nephelometer was powered by a 12 volt DC supply from the beach via a cable buried in the sand. The 12 volts powered the laser power supply directly and was converted by a Burr-Brown 520/25 D.C.-D.C. converter to ± 15 V D.C. for use by the divider circuit and op amps. No other components of the nephelometer required power from external sources.

III. EXPERIMENT

The data discussed in this paper were taken as part of a larger experiment conducted from 15 March-30 April 1977 in the Southern California Bight Area. The overall experiment was designed to test and evaluate the instrumentation systems to go aboard SEASAT which will remotely measure wind, waves, and sea surface temperature. These instruments were flown aboard NASA airplanes. A major ground truth program was simultaneously conducted. As part of the experiment, waves, currents and sediment transport were measured at Torrey Pines Beach as described below.

A five-element, linear array of pressure sensors was placed offshore along the 10-m contour to measure wave energy and direction. Inshore of this array within the surf zone, three instrument support towers were placed. The instrument towers were 6.3 cm outside diameter steel pipes which were 3.6-m high with a 1.0-m baseplate and 0.6-m steel pipe extension. A typical tower and sensor arrangement is shown in Figure 3. The towers were placed on a line perpendicular to the shore and spaced 25 m apart. They were erected during low tide when the beach was easily accessible. The measurements were then conducted at high tide. The tidal range at Torrey Pines Beach is typically two meters.

A surface piercing capacitance wave gauge and a two-component electromagnetic flow meter were mounted on each tower. The nephelometer was also installed on the second support tower as shown in Figure 3. To the north of the towers was an array of 6 flow meters which was used to depict the areal and temporal variation in the alongshore currents. Resistance wire run-up meters were installed in the swash zone at four locations. All instrumentation was battery operated.

The flow meters were Marsh-McBirney Model 511 Electromagnetic Current meters, which operate on Faraday's principle of electromagnetic induction. Each probe measured water velocity in two orthogonal directions. The flow meters were calibrated with an oscillating platform attached to an eccentric arm driven by a variable speed motor. Measurement accuracy was determined to be ±0.005 m/sec during calibration.

The off-shore pressure sensor outputs were telemetered directly to the Shore Processes Lab at Scripps Institute which was located one mile south. All data from the other instruments was cabled to one of two transmitting stations on the beach where it was then telemetered to Scripps and recorded. Later the data was digitized for use in computer analysis.

All of the above instruments except the nephelometer were placed in position prior to high tide on 9 March. The nephelometer was installed on 14 and 15 March. Data was collected from all of the instruments, except the nephelometer, during high tide on 9, 10, 11, and 16 March. Data was collected from all of the instruments on 17, 18, 19, 21, and 23 March with the exception of the nephelometer which became inoperative at 0845 on 19 March.

During the course of the main experiment a number of sub-experiments were also conducted. A radar was installed at the top of the cliff overlooking Torrey Pines Beach at an elevation of approximately 90 m during the month of March. The radar images were photographed and show the refracting wave patterns.

Large scale sediment transport experiments were conducted on 11, 21, and 23 March. Bed load transport was measured by tracing the movement of fluorescent dyed sand using the methods described by Komar and Inman (1970). Suspended sediments were measured in situ by swimmers using a mechanical water sampling device which sampled water at 5 equal intervals from the bottom to 1 m. Many of these samples were taken concurrently with and in the vicinity of the nephelometer in order that a comparison of the two methods could be made. During these sediment transport studies, Lagrangian floats made from wine bottles weighted by sand were placed in the surf zone and followed to determine average longshore current speeds.

IV. RESULTS

The nephelometer was designed to obtain a time series of suspended sediments at any one of three levels in the surf zone while an actual sample of the suspended sediments was being taken. While data was being collected by the nephelometer, waves and velocity measurements were made in an effort to define the environment and determine the forcing functions that caused the suspended sediments.

As these experiments were initial attempts to utilize the nephelometer, difficulties were encountered that could not be corrected in the field. The mean output voltage of the nephelometer was higher than anticipated at the start of data collection, and it continued to slowly rise over the entire period of time the nephelometer was used. Because of this, a negative bucking voltage had to be applied to the output signal in order to bring it within the ± 5v recording limitations of the recording facilities at Scripps Institute. This voltage fluctuation remains unexplained but is probably related to the water leak in the nephelometer which eventually resulted in its failure. These problems made the absolute calibration of the nephelometer difficult. Hence, the output of the nephelometer was used to infer the time variation of the suspended sediment concentrations only; the actual mean concentrations as measured from the three levels were used to determine the variation with elevation.

It should be noted that it was not possible to differentiate positively whether the scattered light intensity was due to suspended sand and other scatterers such as bubbles.

A. TIME SERIES ANALYSIS

All equipment was operational on 17, 18, and 19 March. Using the IBM 360 computer at the Naval Postgraduate School, spectra and cross-spectra were calculated for the nephelometer and the horizontal velocity components for these dates and at several elevations for a total of seven time series (see Appendix A). A typical example of spectra for the nephelometer and horizontal component oriented in the on-offshore direction for 18 March is shown in Figure 6. During this run, the water was sampled at 51 cm above the bottom. The mean depth of the water was 1.5 m. The waves were plunging-spilling breakers having height of approximately 1.6 m. Tower 2, on which the nephelometer was mounted, was located approximately 35 m shoreward of the breaker point at about the middle of the surf zone.

A mean value was calculated for all data sets and the data were linearly de-trended to exclude the rise and fall of the tide. Correlation functions were calculated for 24 minute records and smoothed with a Parzen window. The smoothed correlation functions were Fourier transformed to obtain the power and cross spectra. The coherence and phase were calculated from the cross spectral estimates.

The maximum lag time in calculating the correlation functions was taken as five percent of the record giving a

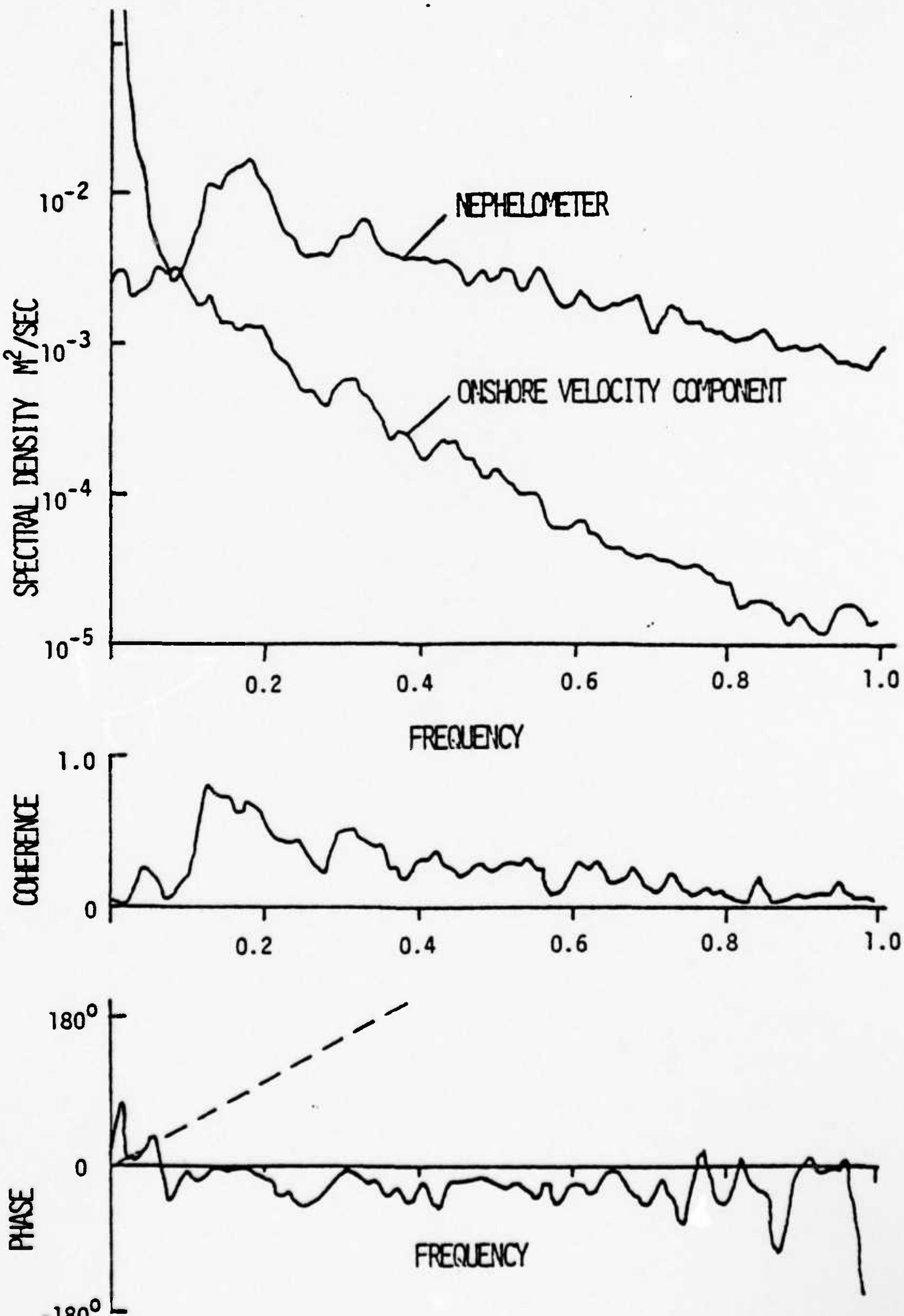


Figure 6. Nephelometer and On-offshore Horizontal Velocity Spectra.

spectral bandwidth resolution of 0.007 Hz and resulting in 40 degrees of freedom for each spectral estimate. The 90 percent confidence limits for 40 degrees of freedom using a chi-square distribution are between 0.72 and 1.51 of the measured power spectral estimates.

The horizontal velocity spectrum in Figure 6 shows an energy peak at 0.06 Hz corresponding to a wave period of 16 seconds. The waves were fairly broad band as reflected in the velocity spectrum. A very low frequency peak is also identified corresponding possibly to surfbeat. The nephelometer spectrum shows a near DC peak due to slow variations (compared to the length of record), a valley at the wave peak, and then a fairly broad maximum at 0.12- .17 Hz. The peak in the nephelometer appears to occur at frequencies corresponding very closely to the first harmonic of the wave spectrum peak.

A coherency squared (referred to hereafter as coherence) minimum occurs at the frequency of the wave energy maximum. Then a maximum coherence of 0.8 occurs at the frequency corresponding to the maximum in the nephelometer spectrum. The high coherence values indicate reasonably good correlation between nephelometer output and the on-offshore horizontal velocities.

The occurrence of maximum light scattering at twice the wave frequency might be interpreted in several ways. In laboratory suspended sediment studies, Bhattacharya (1971) found that two or more maxima occurred during each wave period for monochromatic waves over rippled bottoms. During both the forward and backward motion of the particle velocities under the waves, a burst of sediment was observed to be thrown upward into the fluid due to a vortex generated just downstream of each ripple crest. The maximum sediment concentrations and height above the bed occurred well after the maximum velocity under the crest of the wave as time was required for the vortex and entrained sediments to diffuse upward into the water column. Hence, the maximum concentrations occurred approximately 90° out of phase with the waves. Inside the surf zone, the bed was flat and the ripples were planed off by the more intense flow. Vortex generation was not as strong in the absence of the bottom perburbations caused by the ripples, but none-the-less a similar mechanism would be expected. Another explanation is that clouds or patches of particulates composed of sand, detritus or bubbles were simply advected back and forth and sampled twice during the passage of each wave due to the forward and backward motion. It is concluded that the scattered light is related to the velocity of the flow because maxima occur twice during a wave period for both parameters; the suspended sediments do not differentiate between forward or backward flow. There doesn't appear to be a correlation with wave height or pressure as the pressure has only one maximum during a wave period.

The scattered light and the horizontal water particle velocities were measured to be in-phase at the coherence maximum. An increasing phase lag would be expected with frequency because there was approximately a one second time lag between when the sediment laden water entered the nozzle and when it arrived at the nephelometer located approximately 2 meters up the pipe. Consider a single frequency component where the horizontal velocity is given by

$$v = V \cos 2\pi f t$$

and the scattered light by

$$s = A \cos 2\pi f \left(t + \frac{x}{U}\right)$$

where x is the distance between the nozzle and the nephelometer and U is the velocity of flow in the pipes. The phase difference due to the pumping distance is given by

$$\Delta\phi = \phi_s - \phi_v = \frac{2\pi f x}{U}$$

The expected phase difference is plotted as a dotted line in Figure 6 on the phase spectrum. The difference between the dotted line and the measured phase difference is approximately 90° at the coherence maximum indicating the suspended sediments lag the horizontal velocities by this amount; this is consistent with the measurements by Bhattacharya (1971).

Examples of spectra for the nephelometer and horizontal component of flow oriented in the longshore direction (see Appendix A) show the same spectrum as the on-offshore flow for the nephelometer with the peak in scattering occurring at the first harmonic of the wave spectrum peak. The energy peak for the longshore flow, however, is seen to occur at a much lower frequency than the on-offshore flow. This was expected due to the much longer periods of the longshore flows observed. It can also be seen that very low coherence exists between the nephelometer and longshore flow. This further indicates that the scattering fluctuations were caused by the on-offshore flows associated with the waves, rather than the longshore flows.

B. MEAN SEDIMENT CONCENTRATIONS

A total of 30 suspended sediment samples were collected on 17, 18, 19, 21, and 23 March (see Table I). The sediment laden water pumped from a selected intake nozzle was discharged into a large settling container on the beach. The sampling time was approximately two minutes--the time to fill the container. After the sand had settled out of suspension the water was carefully poured off. The sand sample was later dried and weighed to obtain the concentration in grams of sand per liter of sea water. Analysis showed the samples were composed of a well sorted, fine grained, quartz sand. At least 50 percent of each sample had a grain size from .177 mm to .125 in diameter (2.5 Φ to 3 Φ). The remaining portion of each of the samples was almost entirely in the .250 mm or 0.88 mm diameter size ranges (2.0 Φ and 3.5 Φ respectively).

The mean measured sediment concentrations are summarized in Figure 7. It is pointed out that the measurements at various levels on the same day were not taken at the same time but generally within a one-hour period. Most of the

TABLE I

Suspended Sediments, Torrey Pines Beach

17 - 23 March 1977

Date (March)	Time Local	g(Sample) / L (Vol of water)	Intake Height from Bottom z (CM)	Depth d (CM)	Relative intake height from bottom z/d	Bed Shear Stress $\tau/\rho\kappa$
17 Thu	0853	.202	10	100	.1	1.46
17	0904	.152	10	100	.15	1.24
18 Fri	0810	.05	51	150	.34	.919
18	1000	.104	10	150	.15	.596
18	1032	.127	10	150	.15	.620
19 Sat	0751	.101	51	139	.37	1.09
19	0754	.06	51	139	.37	1.10
19	0855	.075	21	139	.151	1.04
19	0902	.130	21	139	.151	.911
19	0906	.245	21	139	.151	1.21
19	0952	.316	6	139	.043	.859
19	0956	.251	6	139	.043	1.33
19	1000	.302	6	139	.043	1.65
19	1004	.285	6	139	.043	.81
21 Mon	0917	.143	15	81	.185	No data
21	0920	.113	15	81	.185	No data
21	0924	.162	15	81	.185	No data
21	0928	.114	15	81	.185	No data
21	1020	.126	15	81	.185	.83
21	1020	.129	15	81	.185	.85
21	1050	.154	45	81	.555	.65
21	1053	.095	45	81	.555	.52
21	1107	.056	45	81	.555	.521
21	1120	.101	15	81	.185	.583
23 Wed	1104	.293	15	57	.263	.308
23	1120	.096	15	57	.263	.195
23	1136	.110	15	57	.263	.240
23	1153	.064	45	57	.789	.154
23	1213	.139	45	57	.789	.180
23	1225	.062	45	57	.789	.162

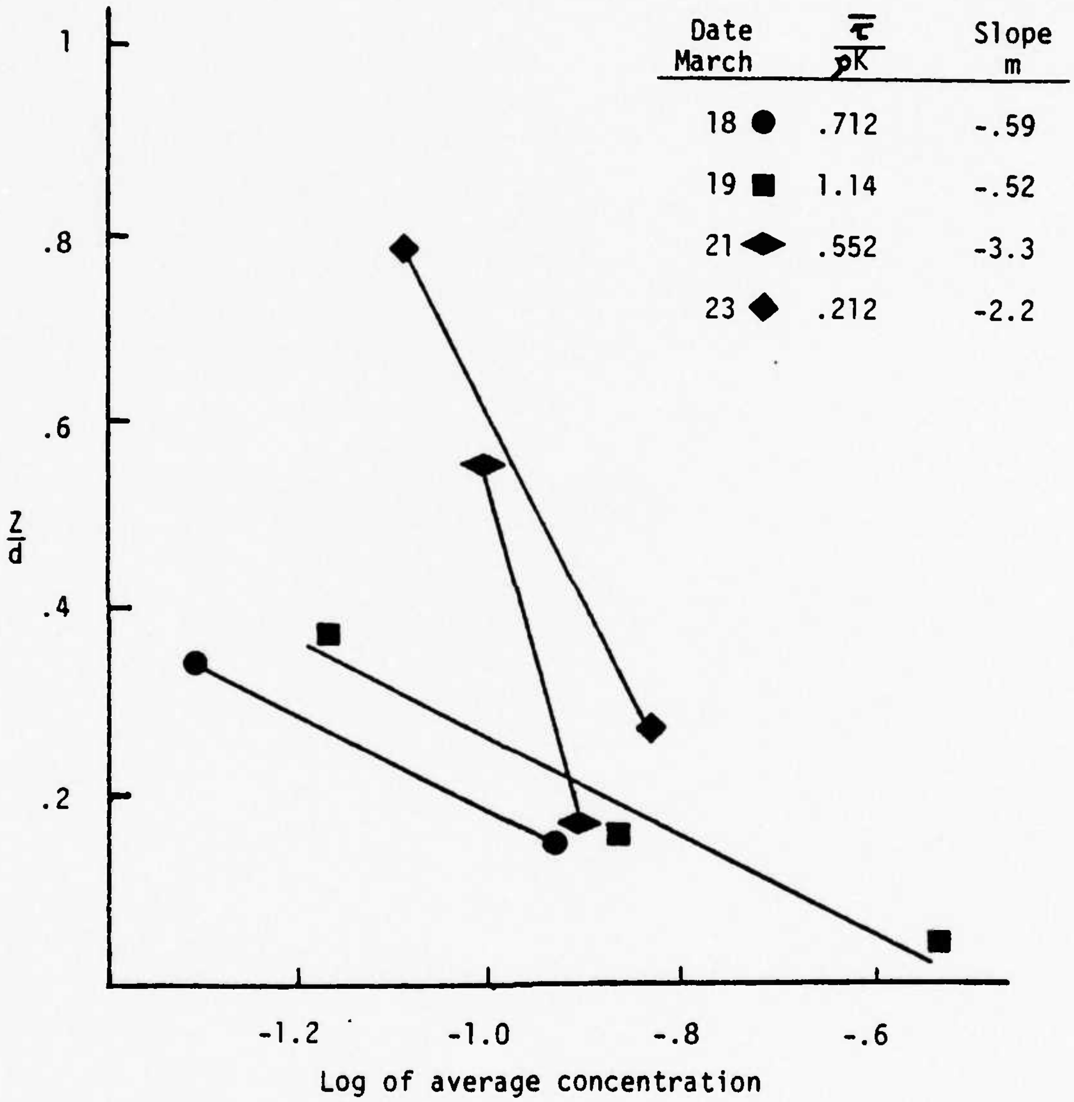


Figure 7. Mean Sediment Concentration as a Function of Depth.

points are the average of three or more two-minute samples. The sediment concentrations are plotted against relative depth, z/d. There was a definite decrease of sediment concentration with distance off the bed. The concentrations varied between 0.05 to 0.32 gm per 1 of sea water. The mean sand concentration taken by the sampling system compared favorably with instantaneous sand samples taken with the five-level sampling device mentioned earlier. A time averaged bed shear stress was computed over the same time intervals that the sand samples were taken, using the longshore and onshore velocity components (u and v)

$$\frac{\bar{\tau}}{\rho K} = \left(\overline{u^2 + v^2}\right)^{1/2}$$

where the overbars indicate time averaging; ρ is the density of sea water and K is the bed shear stress coefficient. The slopes of the lines on the graph of the relative depth, z/d, of the sample vs. the log of the average sand concentration at each level for 18, 19, 21, and 23 March (see Figure 7) demonstrates the magnitude of the exponential decrease in sand concentration with height off of the bottom for each of the four days. Based on past experiments with which the observed data are not inconsistent, the concentration as a function of depth has the form

$$C(z) = C_0 e^{-m z/d}$$

where the maximum concentration at the bed, C_0, would be expected to be a function of the bed shear stress, and the slope, m, would be expected to be a function of the bed shear stress and fall velocity. Increasing bed shear should increase the total concentration. The fall velocity and flow intensity determine how long the sediments stay in suspension.

A comparison of slope, m, in Figure 7, with the average bed shear stresses for each day (see Table I and Figure 7) indicates that lower slopes relate to days of high bed shear stress and higher slopes are apparent during days of lower stress. This compares favorably with the observed surf conditions for the days considered. 21 and 23 March were generally calmer days with lower wave heights, lower velocity currents, and consequently lower bed shear stress.

V. CONCLUSIONS

1. A nephelometer was designed to optically measure suspended sediments and to obtain a direct mean suspended sediment concentration measurement in order to have an *in situ* calibration.

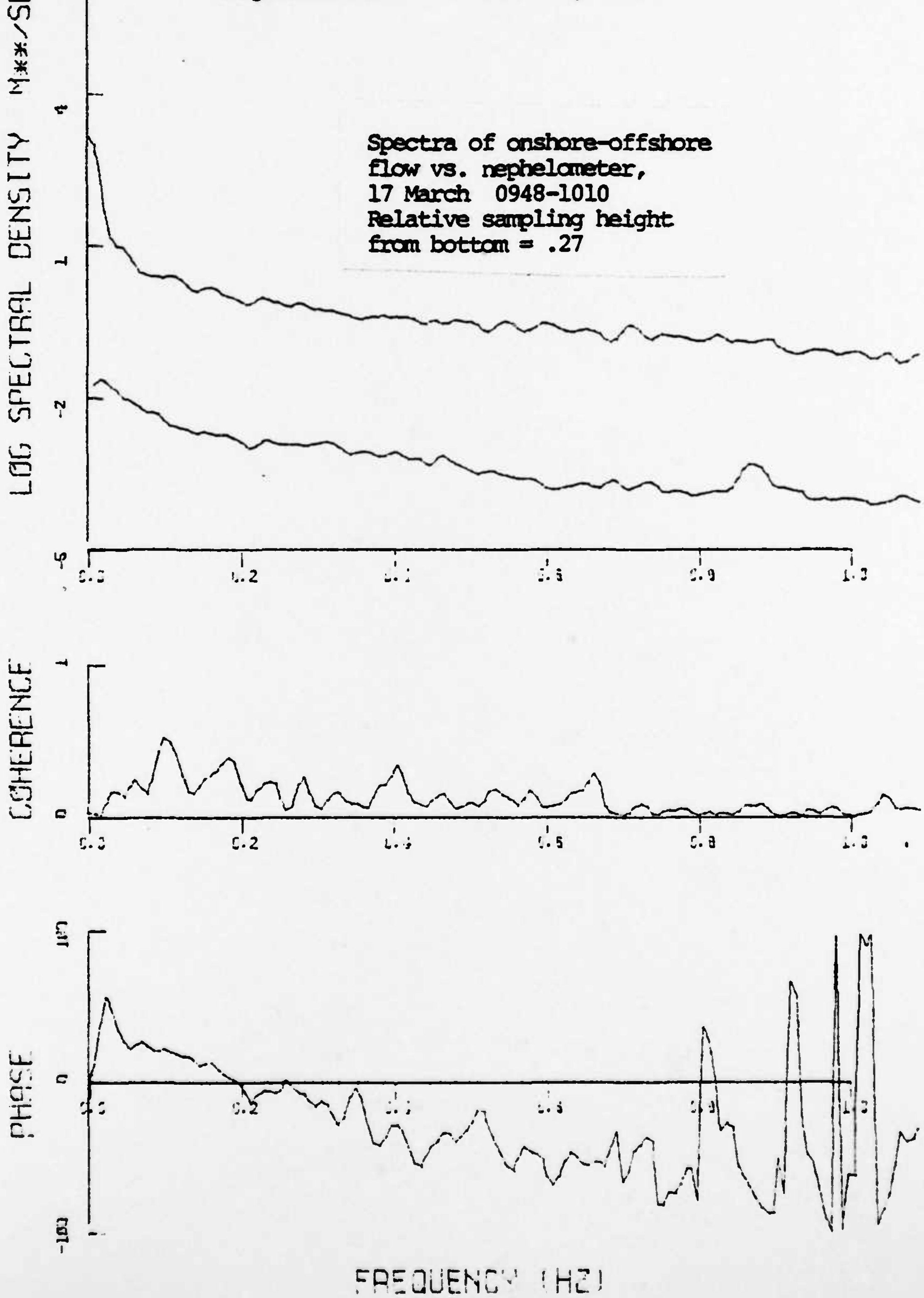
2. Spectra and cross-spectra of the nephelometer signal and horizontal on-offshore velocities showed the maximum light scattering, inferring suspended sediment concentration, occurred at twice the average wave frequency. The coherence between the nephelometer and on-offshore horizontal velocity was low at the peak of the velocity spectrum (average wave period) and had a maximum (ranging above 0.7) at twice the average wave period. The phase spectra indicated the suspended sediments lagged the horizontal velocity by approximately 90°. It is concluded that there was a definite correlation of the nephelometer measurements and on-offshore horizontal velocities and that the nephelometer responded to both forward and backward flow.

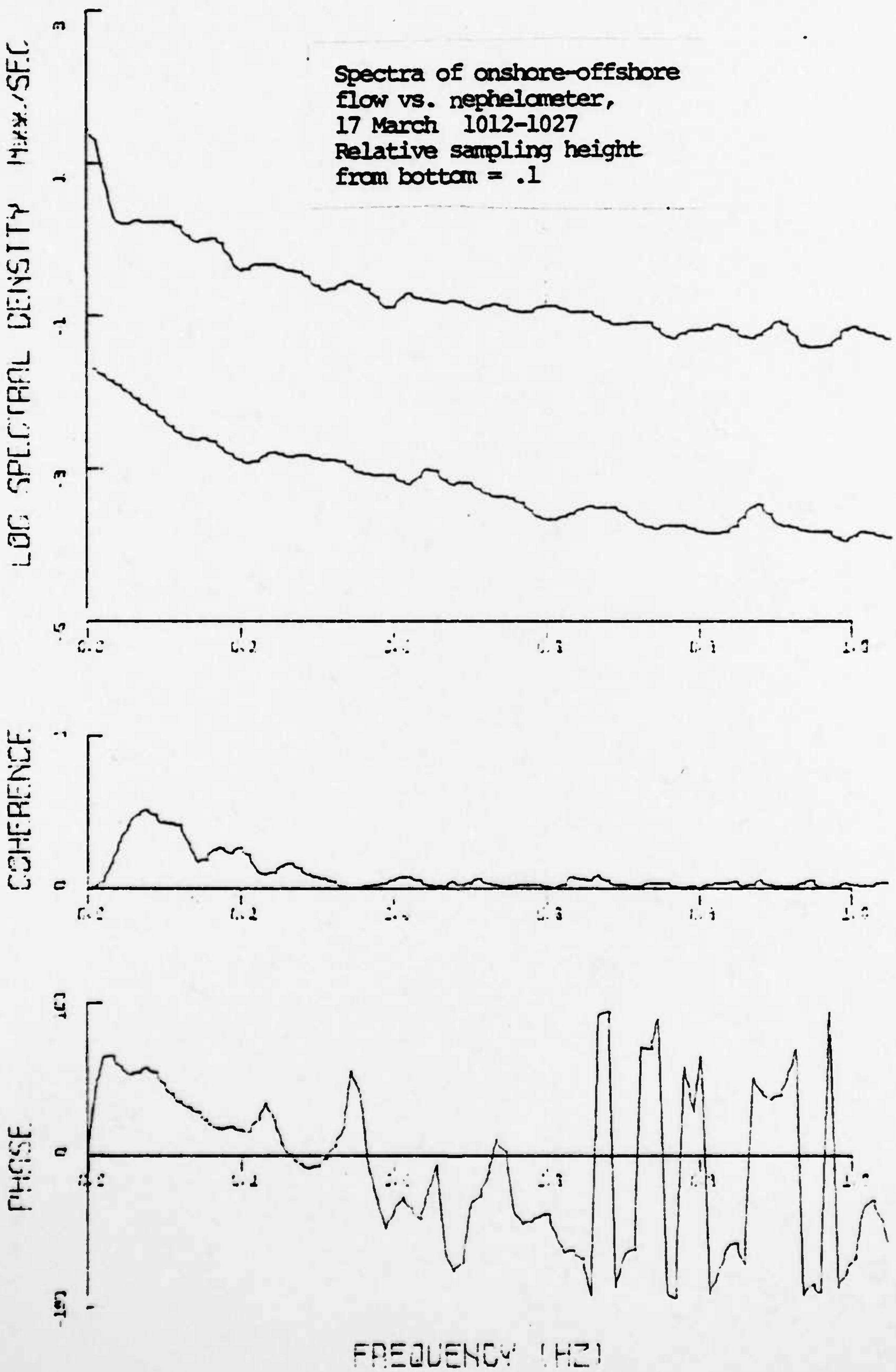
3. Low coherence existed between the longshore flow and the nephelometer,indicating that the scatter fluctuations were caused by the on-offshore flows associated with the waves, rather than by the longshore flow.

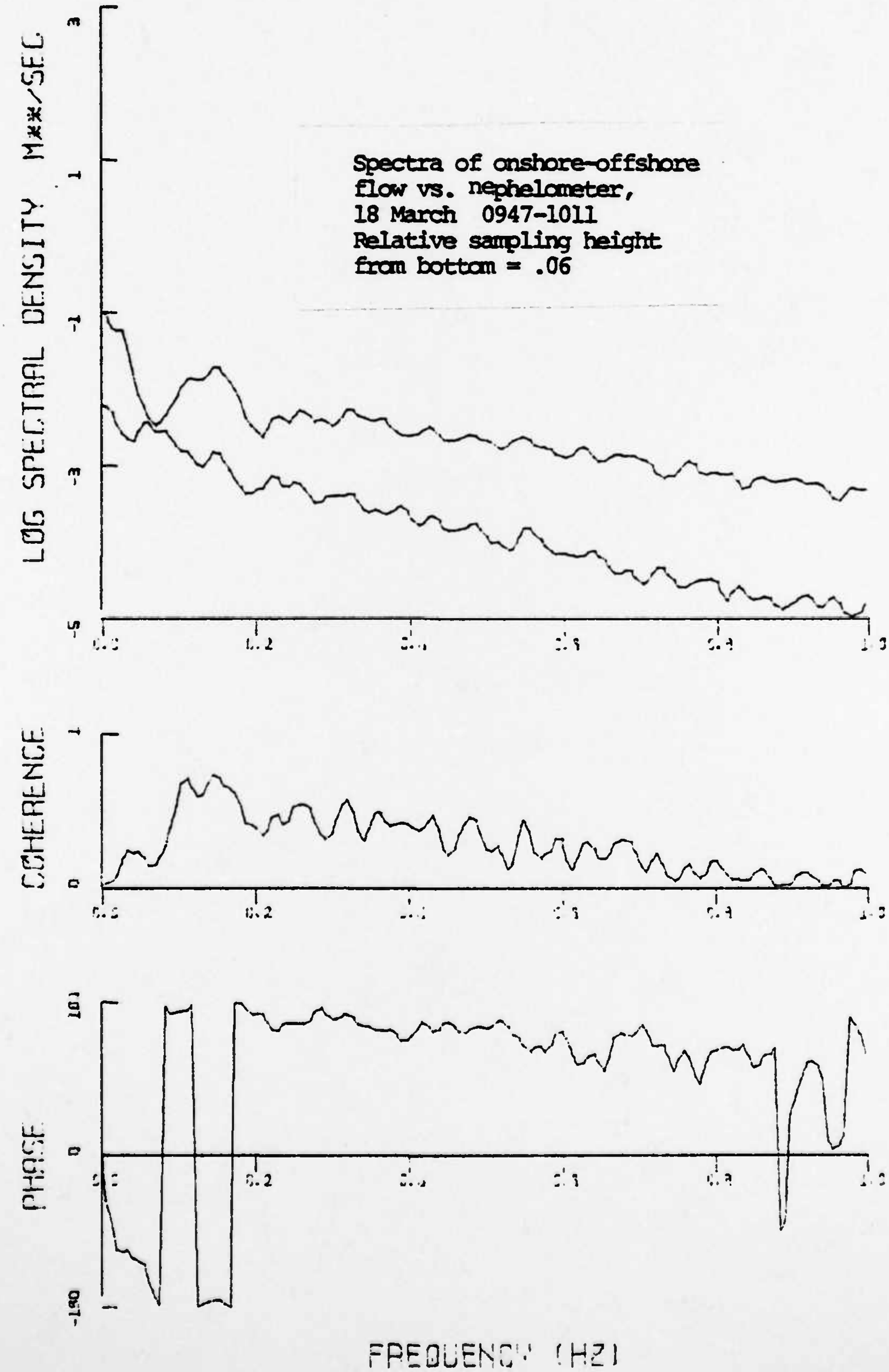
4. The mean sediment concentrations decreased with distance off the bed and were generally related to the mean bed shear stress.

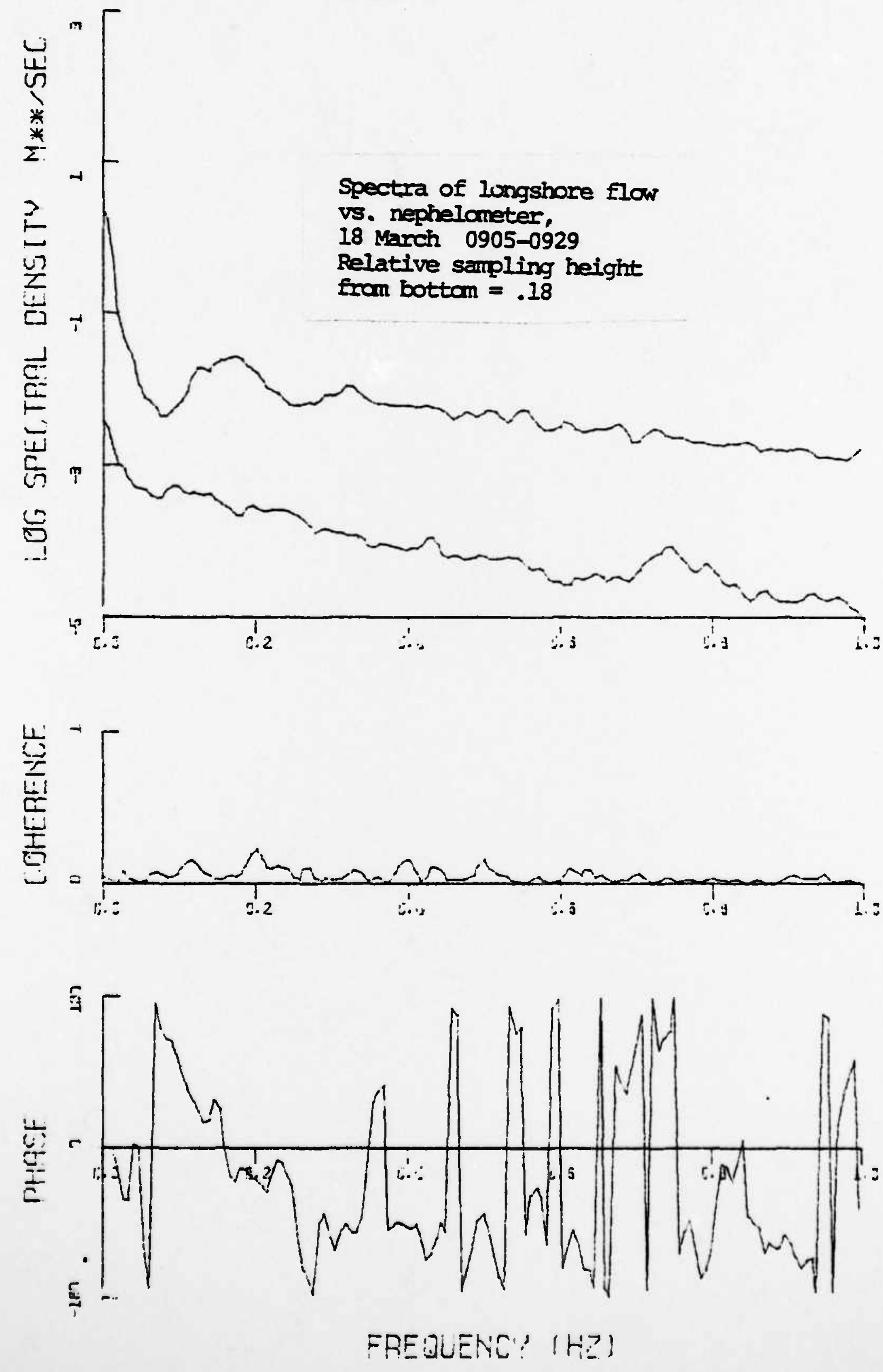
APPENDIX A

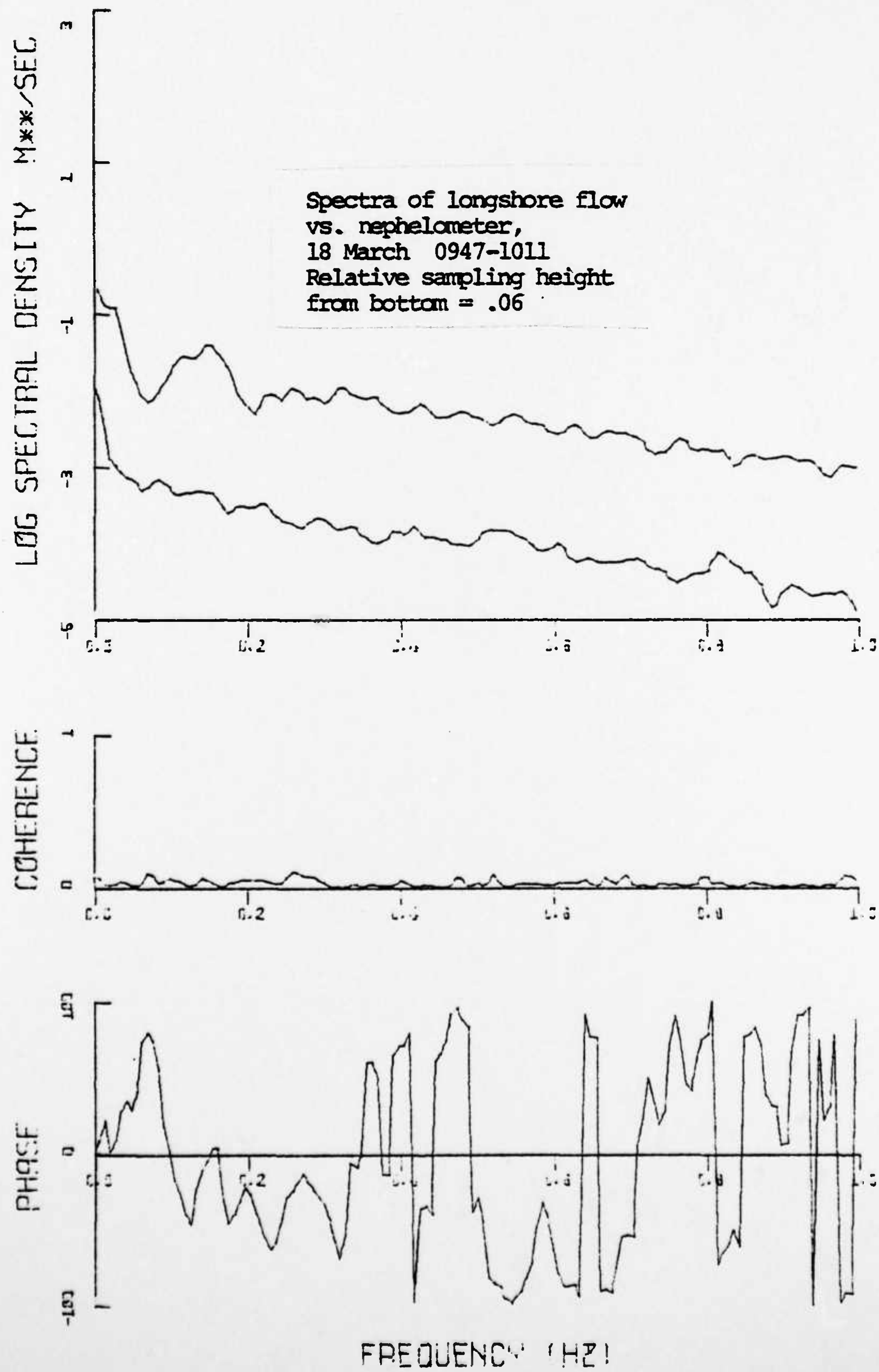
Nephelometer and Flow Spectra

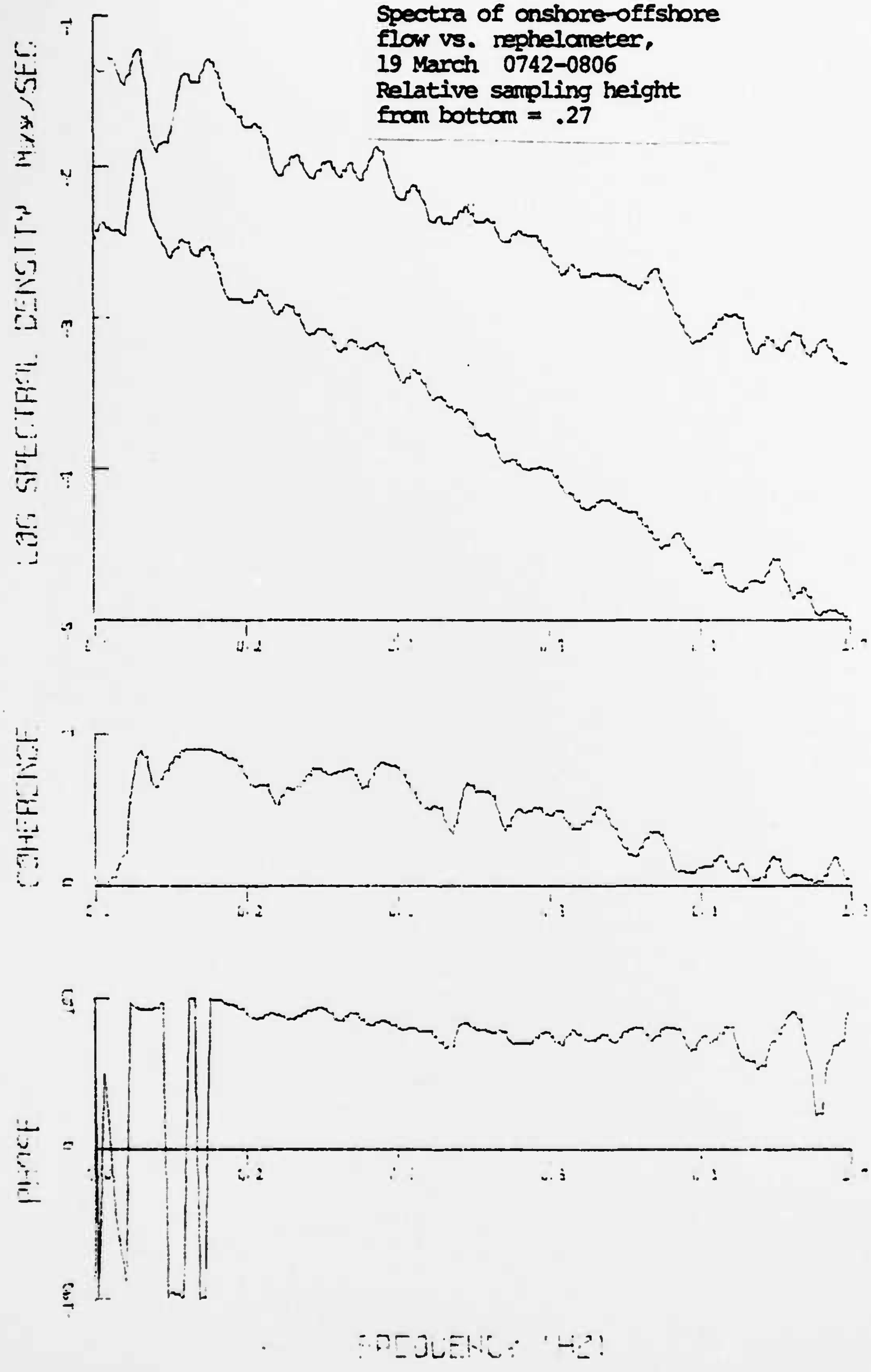


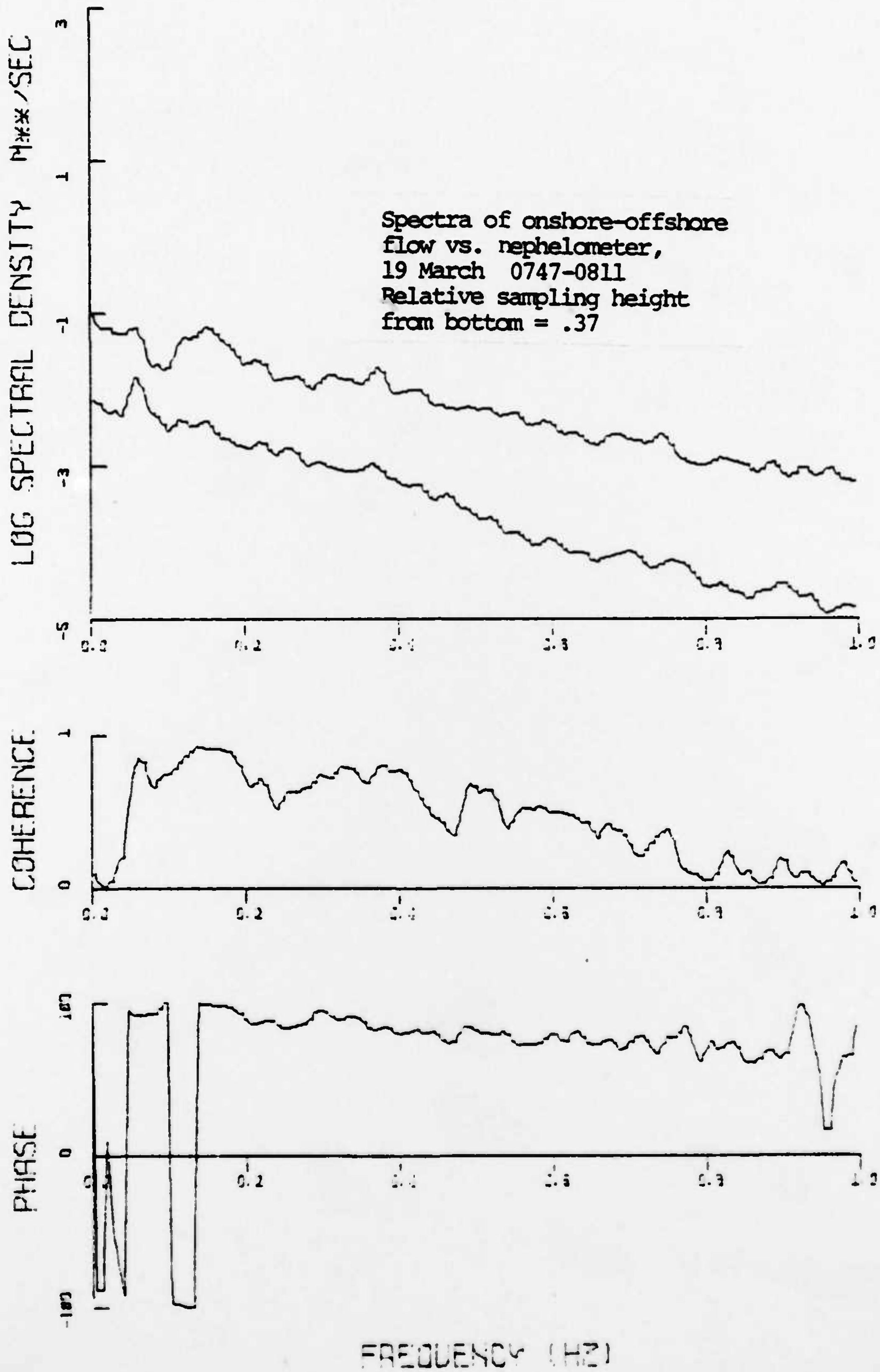

Spectra of onshore-offshore
flow vs. nephelometer,
17 March 1012-1027
Relative sampling height
from bottom = .1
LOG SPECTRAL DENSITY
3
1
-1
-3
-5
COHERENCE
1
0
PHASE
180
0
-180
FREQUENCY (HZ)

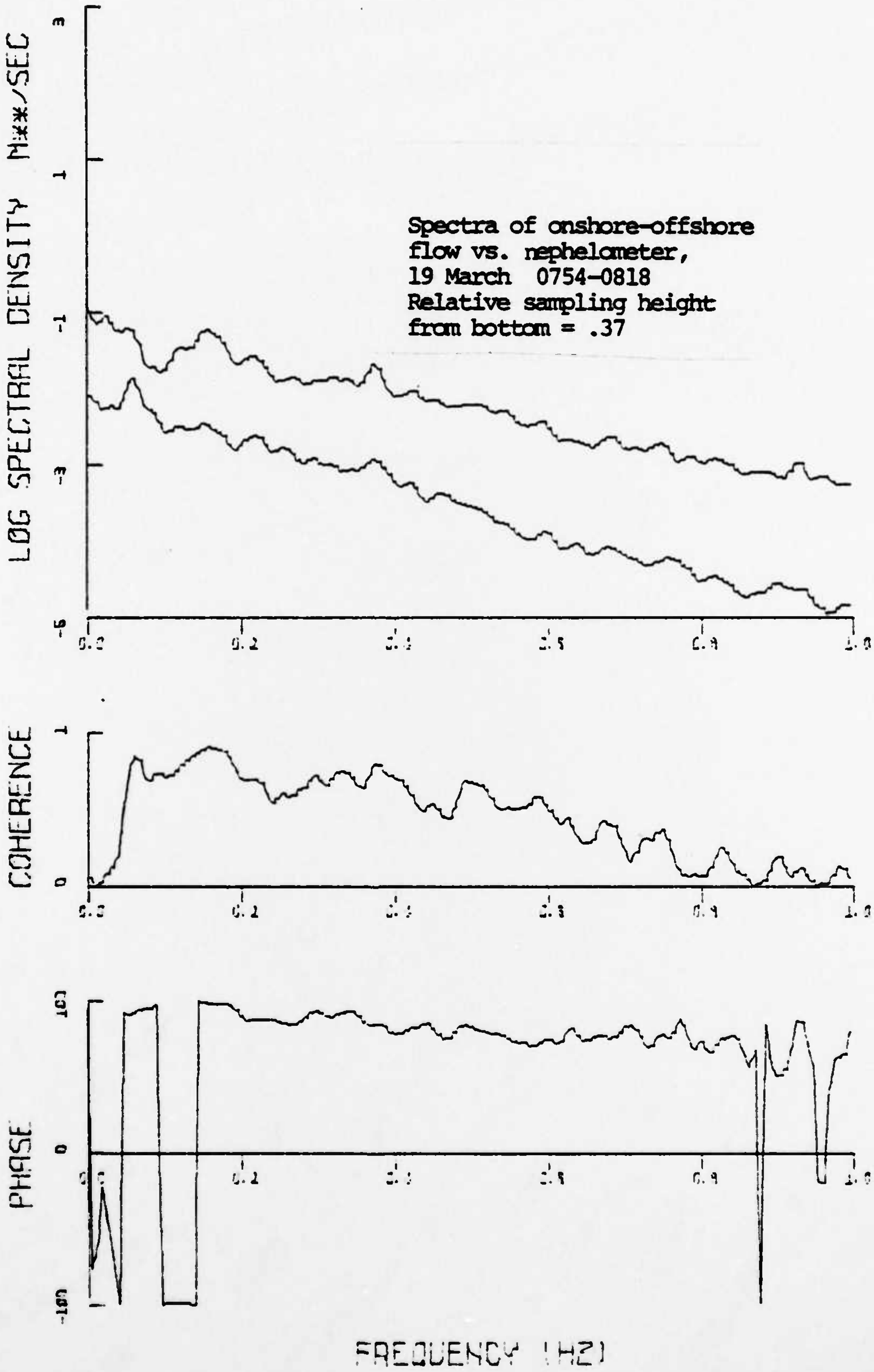

Spectra of onshore-offshore
flow vs. nephelometer,
18 March 0947-1011
Relative sampling height
from bottom = .06
LOG SPECTRAL DENSITY M**/SEC
3
1
-1
-3
-5
0.2
COHERENCE
1
0
0.2
PHASE
0
0.2
FREQUENCY (HZ)

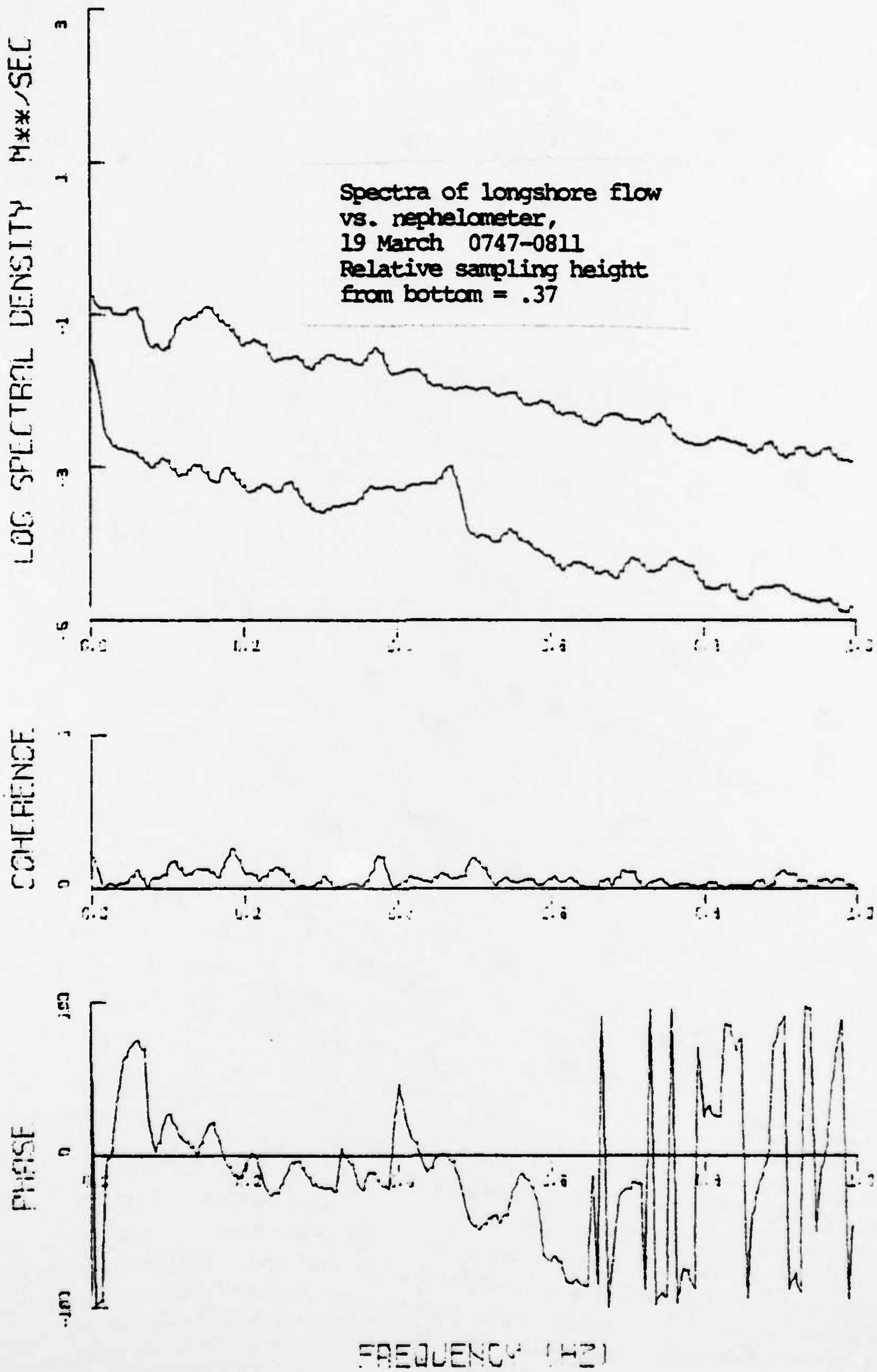

Spectra of longshore flow
vs. nephelometer,
18 March 0905-0929
Relative sampling height
from bottom = .18
LOG SPECTRAL DENSITY M**/SEC
COHERENCE
PHASE
FREQUENCY (HZ)

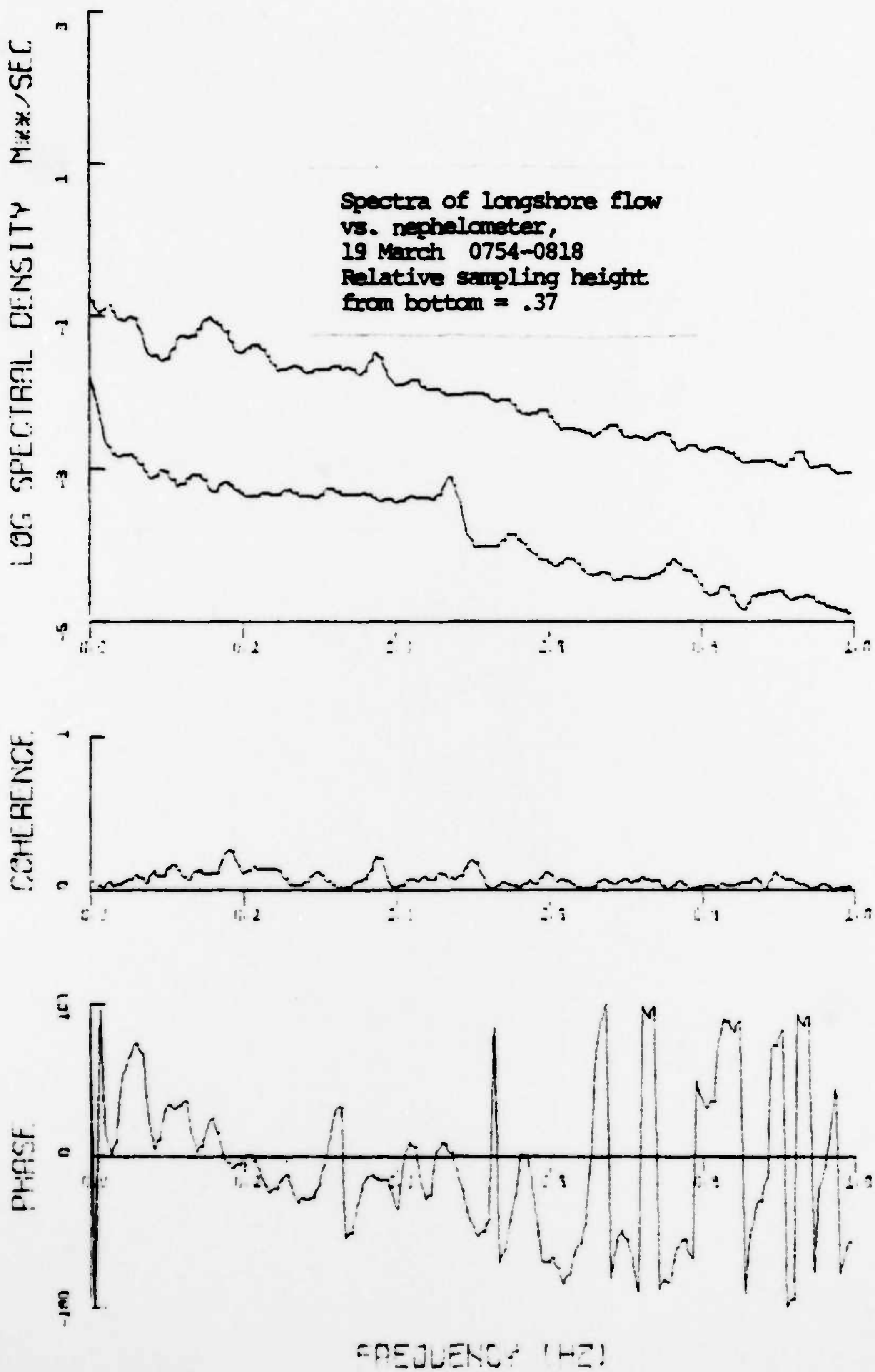

Spectra of longshore flow
vs. nephelometer,
18 March 0947-1011
Relative sampling height
from bottom = .06
LØG SPECTRAL DENSITY M**/SEC
3
1
-1
-3
-5
COHERENCE
1
0
PHASE
180
0
-180


Spectra of onshore-offshore
flow vs. nephelometer,
19 March 0742-0806
Relative sampling height
from bottom = .27


LOG SPECTRAL DENSITY M**/SEC
3
1
-1
-3
-5
Spectra of onshore-offshore
flow vs. nephelometer,
19 March 0747-0811
Relative sampling height
from bottom = .37
COHERENCE
1
0
PHASE
0
FREQUENCY (HZ)


Spectra of onshore-offshore
flow vs. nephelometer,
19 March 0754-0818
Relative sampling height
from bottom = .37
LØG SPECTRAL DENSITY M**/SEC
3
1
-1
-3
-5
COHERENCE
1
0
PHASE
180
0
-180
FREQUENCY (HZ)


LOG SPECTRAL DENSITY M**/SEC
3
1
-1
-3
-5
Spectra of longshore flow
vs. nephelometer,
19 March 0747-0811
Relative sampling height
from bottom = .37
COHERENCE
0
PHASE
180
0
-180
FREQUENCY (HZ)


LOG SPECTRAL DENSITY
Spectra of longshore flow
vs. nephelometer,
19 March 0754-0818
Relative sampling height
from bottom = .37
COHERENCE
PHASE
FREQUENCY (HZ)

BIBLIOGRAPHY

Beach Erosion Board, Interim Report, U.S. Army Corps of Engineers, Washington, D.C., 1933.

Bhattacharya, P.K., "Sediment Suspension in Shoaling Waves," Ph.D. Thesis, University of Iowa, 1971.

Brenninkmeyer, B.M., Synoptic Surf Zone Sedimentation Patterns, Ph.D. Thesis, University of Southern California, Los Angeles, 1973.

Brenninkmeyer, B.M., "Mode and Period of Sand Transport in the Surf Zone," Coastal Engineering, V. 2, p. 812-827, 1974.

Das, M., "Mechanics of Sediment Suspension Due to Oscillatory Water Waves," Symposium to Honor H.A. Einstein, edited by H.W. Shen, Chapter II, 1972.

Dean, R.G., "Heuristic Models of Sand Transport in the Surf Zone," Proceedings of Conference on Engineering Dynamics in the Surf Zone, Sydney, Australia, 1973.

Fairchild, J.C., "Suspended Sediment in the Littoral Zone at Ventnor, New Jersey, and Nags Head, North Carolina," U.S. Army Corps of Engineers Coastal Engineering Research Center Report TP77-5, May 1977.

Fukushima, H., and Mizoguchi, Y., "Field Investigation of Suspended Littoral Drift," Coastal Engineering in Japan, Vol. 1, p. 131-134, 1958.

Gibbs, R.J., Suspended Solids in Water, pp. 3-15 and 101-109, Plenum Press, 1973.

Homma, M., Horikawa, K. and Kajima, R., "A Study of Suspended Sediment Due to Wave Action," Coastal Engineering in Japan, V. 3, p. 101-122, 1965.

Kennedy, J. F. and Locher, F.A., "Sediment Suspension by Water Waves," Waves on Beaches and Resulting Sediment Transport, R.E. Meyer, ed., Academic Press, 1972.

Jerlov, N.G., Optical Oceanography, Elsevier Publishing Company, 1968.

Komar, P.D., and Inman, D.L., "Longshore Sand Transport on Beaches," Journal of Geophysical Research, V. 75, No. 30, 20 October 1970.

Longinov, V., "Determination by a Photo-electric Method of Sand Suspension Concentration in the Littoral Zone During Waves," Gosudarstvennyi proektro-konstruktorskii i Naucho-issledovatel' skii Institut Morskogo Transporta, V. 20/26, p. 82-92, 1968.

Nakato, T., Locher, F.A., Glover, J.R. and Kennedy, J.F., "Wave Entrainment of Sediment from Rippled Beds," Journal of the Waterway Port Coastal and Ocean Division, V. 103, No. WW 1, p. 83-99, February 1977.

Nordstrom, C.E. and Inman, D.L., "Sand Level Changes on Torrey Pines Beach, California," U.S. Army Corps of Engineers Coastal Engineering Research Center Report MP11-75, December 1975.

Raudkivi, A.J., Loose Boundary Hydraulics, p. 123-135, Pergamon Press, 1967.

Thornton, E.B., "Distribution of Sediment Transport Across the Surf Zone," Proceedings of the 13th International Conference on Coastal Engineering, ASCE, Chapter 55, p. 1049-1068, 1973.

U.S. Interagency Committee on Water Resources, "Measurements and Analysis of Sediment Loads in Streams," Report No. 14, 1963.

Wang, H. and Liang, S.S., "Mechanics of Suspended Sediment in Random Waves," Journal of Geophysical Research, V. 80, No. 24, p. 3488-3494, 20 August 1975.

Watts, G.M., "Development and Field Tests of a Sampler for Suspended Sediment in Wave Action," Beach Erosion Board Technical Memorandum No. 34, U.S. Army Corps of Engineers, Washington, DC, 1953.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library (Code 0212) Naval Postgraduate School Monterey, California 93940	2
3.	Assoc. Professor E. B. Thornton, Code 68Tm Department of Oceanography Naval Postgraduate School Monterey, California 93940	2
4.	Asst. Professor S. P. Tucker, Code 68Tx Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
5.	Chairman, Department of Oceanography, Code 68 Naval Postgraduate School Monterey, California 93940	3
6.	LT William D. Morris, USN 1123 Busac Avenue Jacksonville, FL 32205	3
7.	Oceanographer of the Navy Hoffman Building No. 2 200 Stovall Street Alexandria, Virginia 22332	1
8.	Office of Naval Research Code 410 NORDA NSTL Station, Mississippi 39529	1
9.	Dr. Robert E. Stevenson Scientific Liaison Office, ONR Scripps Institution of Oceanography La Jolla, California 92037	1
10.	Library, Code 3330 Naval Oceanographic Office Washington, DC 20373	1
11.	SIO Library University of California, San Diego P.O. Box 2367 La Jolla, California 92037	1

12. Department of Oceanography Library | 1
University of Washington
Seattle, Washington 98105

13. Department of Oceanography Library | 1
Oregon State University
Corvallis, Oregon 97331

14. Commanding Officer | 1
Fleet Numerical Weather Central
Monterey, California 93940

15. Commanding Officer | 1
Naval Environmental Prediction Research Facility
Monterey, California 93940

16. Department of the Navy | 1
Commander Oceanographic System Pacific
Box 1390
FPO San Francisco 96610

17. Director, Naval Oceanography | 1
and Meteorology
National Space Technology Laboratories
NSTL Station, Mississippi 39529

18. Naval Oceanographic Research | 1
and Development Activity
NSTL Station, Mississippi 39529

19. Dr. D. Inman | 1
A-009
University of California
Scripps Institute of Oceanography
La Jolla, California 92037

20. Dr. R. Sternberg | 1
Oceanography Department
University of Washington
Seattle, Washington 98195

ATE

LMED